Immersive Serious Games for Learning Physics

Joel Gil León

School of Science

Thesis submitted for examination for the degree of Master of Science in Technology.

Orsay, France 31.8.2019

Supervisor

Prof. Tapio Takala (Aalto University)

Advisor

Prof. Jeanne Vezien (Université Paris-Sud)

Aalto University
School of Science

Aalto University
School of Science

Aalto University, P.O. BOX 11000, 00076 AALTO
www.aalto.fi
Abstract of the master's thesis

Author Joel Gil León

Title Immersive Serious Games for Learning Physics

Degree programme ICT Innovation

Major Human-Computer Interaction and Design **Code of major** SCI3020

Supervisor Prof. Tapio Takala (Aalto University)

Advisor Prof. Jeanne Vezien (Université Paris-Sud)

Date 31.8.2019 **Number of pages** 53 **Language** English

Abstract

Gaming in Virtual Reality has been growing at a rapid pace in the last decade with the proliferation of affordable head mounted displays (HMDs) and development frameworks. There has been a lot of research regarding user's spatial mapping, selection and orientation in VR, but so far not a lot of work has been done to measure performance on widgets used for other actions. In this document I aim to analyze two widgets, World in Miniature(WIM) and an isometric 2D display, in a common task in gaming: aiming and shooting at a long distance target. We measured performance from a quantitative perspective by measuring average aiming time and error rate between the widgets, and gathered user feedback to understand which widget the users preferred based on usability and perceived performance. The measured performance showed a significant difference in the error rate between the isometric 2D display and the baseline, but not with the WIM. The qualitative analysis showed that users were confident about their enjoyment of the WIM but more polarized about their opinion on the isometric 2D display. The results can be considered as a starting point to a broader discussion on spatial interaction. In particular we suggest that the importance of operation and manipulation ability of a widget might be more important than the information displayed on the widget itself.

Keywords spatial interaction, HCI, game design, 3D interfaces, design thinking, virtual reality

Preface

I want to thank my supervisor, Prof. Jeanne Vezien, for giving me the freedom to guide my own research. Also to the PhD students at the VENISE lab for their advise, support and insight regarding my work and academic life.

Paris, 31.8.2019

Joel G. L. Engineer

Contents

Abbreviations

API	application programming interface
AR	augmented reality
DOF	degrees of freedom
FOV	field of view
HCI	human-computer interaction
HMD	head mounted display
LIMSI	Laboratoire d'Informatique pour la Mécanique et les Sciences de l'Ingénieur
MR	mixed reality
SDK	application programming interface
UX	user experience
VR	virtual reality

1 Introduction

Virtual Reality is moving forward very fast thanks to the declining prices of hardware as well as the support and commitment from companies such as Microsoft, Google, Facebook, Valve, and others. The idea of using VR for education is not new. Simulation environments have been used for education since the first immersive environment technologies were available. The most common example is in the aviation industry, where pilots need to be trained extensively in an immersive environment before being able to fly a real airplane. Similarly, the use of technology inside a classroom is not new either. Educational Technology, refers to the area looking to facilitate learning through improvement in performance by the creation, use, and management of technological processes or resources [31]. These practices have been in development even before they were formalized. Nevertheless, new media like immersive technology have not been extensively explored outside the industry field. The VENISE team has an opportunity to create and scientifically measure the possible benefits of bringing affordable immersive technologies into the classroom. Moreover, user interaction in these immersive media is a rather new field of research. Any advances, tests and experiments with 3D user interfaces inside an immersive environment is a great opportunity to contribute to this new community [5].

The VENISE team at LIMSI (Laboratoire d'Informatique pour la Mécanique et les Sciences de l'Ingénieur), focuses on research in the areas of Augmented and Virtual reality. An ongoing project with the VENISE team sits at the cross of 3 different broad areas: Physics education, Serious games and Virtual Reality. The team has the support of researchers from Université Paris-Diderot to aid in the development of the didactics of learning physics. This partnership is planned to extend in the long term and possibly continue into experimentation with participants inside real school classrooms in France. The project Immersive Serious Games for Learning Physics, known as JeSeiPa for its french acronym (Jeu Sérieux Immersif Pour L'Apprentissage de la Physique), attempt to join these three areas by leveraging the group's knowledge in immersive technologies (see figure 1). In the short term, the initial goal became that of setting up the basis for the future work. Leveraging a background in software engineering, service design, and user research practices, we worked towards two specific short-term goals: Identifying game elements and general design decisions for the future development; and to implement an experiment to compare 2 different spatial interfaces.

1.1 Research Question

When comparing 2 spatial interfaces, a world in miniature(WIM) and an isometric 2D display, which one offers the better success rate when attempting to hit a target and which one is preferred by the users?

The research question focuses on comparing two display user interfaces aimed at providing a visualization a user as well as target position inside of large areas. With the targets located at a distance far enough from the users that a visualization aid is expected to increase their success rate when attempting point at shoot at them. The

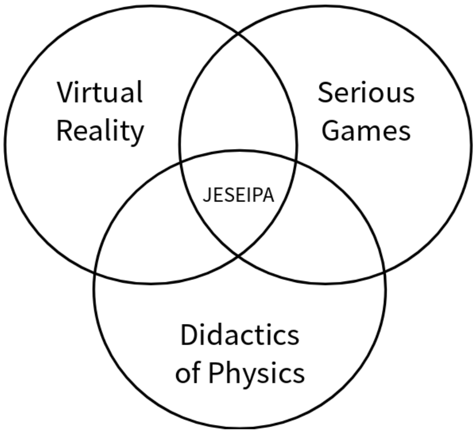

Figure 1: Areas of interest of the Jeseipa project.

comparisons are made in terms of aiming time, success rate, and user preference. Moreover, the study also collects user's feedback on the interface itself and how to improve them. This work aims to better understand the role of spatial interactions in the context of immersive games by comparing a three dimensional interface with a 2D visualization familiar to the current task.

1.2 Structure

This work is organized in different sections covering from theoretical and technological background of the problem. First, we discuss the historical background of the main areas which are worked upon: Virtual Reality, Serious games, and User Interaction in VR. Regarding VR a brief recount of the key developments since 1968 is given. Instead of going through every milestone, we provide a general explanation of its current definition, usage, and references to relevant work. Regarding User Interaction in VR, we provide a brief review of User Interaction as a field and then dive deeper on latest developments in the area of User Interaction in a three-dimensional space, also called Spatial Interaction.

The next section, Game Design, focuses on the structure of the long term project and the work we did using design thinking framework as well as game design frameworks. We explain in detail each of the activities we used to gather and parse information, as well as the brainstorming and ideation process, and finally describe the accepted idea we proposed to the project supervisors.

The following section explains the next step of the internship related to the work on spatial interaction research. We explain the process that led to choosing 2 widgets and background information on each of them. We explain the general goals and the research questions identified. Finally we briefly describe our initial idea on creating a prototype to answer those questions.

Next, we describe all the pieces used to create a prototype: the hardware used, the software architecture selected for development and implementation, the data collection methods, both quantitative (performance) and qualitative (user feedback), and where they were placed in the system. Finally I describe the procedure of the experiment itself.

The next section describes the results divided into quantitative and qualitative. Quantitative data focuses on the performance difference (or lack thereof) between the analyzed widgets. Qualitative data dives deeper into the feedback provided by users at the end of the experiment as well as observations of user behavior while they were performing the tasks. Due to the qualitative results providing a considerably higher amount of data compared to the quantitative, I spend more time describing each of top user feedback and how each issue they encounter behaved. Finally I also describe improvements suggested by the users.

The last section is used to interpret the results in a broader way and what they mean in the general context of spatial user interaction, the JeSeiPa project, and how this work could be extended.

2 Background

2.1 Virtual Reality

Many authors consider the use of the term can be traced back to a science fiction novel, Pygmalion's Spectacles, where the main character describes a wearable device that transports the user to an alternate, virtual reality. The experience in the story involves holographic recordings that incorporate other human senses [40]. This description is key due to the specificity of using a mounted device to project information directly to the person as well as the feeling of being inside of a place which is not the current physical one. Further descriptions of VR through history continue to use the metaphor of devices and the feeling of being somewhere else [10, 24, 20].

Steuer [34] argued that focusing on the hardware was hindering the definition. Instead he proposed defining VR in terms of human experience and leaving outside the hardware. He proposed the use of 2 concepts: Presence and Telepresence. He pointed at Gibson's [15] definition of presence as "the experience of one's physical environment; it refers not to one's surroundings as they exist in the physical world, but to the perception of those surroundings as mediated by both automatic and controlled mental processes". Extending this definition, he proposes telepresence to be "the experience of presence in an environment by means of a communication medium". With these concepts in mind, he proposed Virtual Reality to be a real or simulated environment in which a person experiences telepresence. Steuer [34] also proposed that there are 2 dimensions to measure telepresence: Vividness and Interactivity. Referring, respectively, to the ability of a technology to produce environments that are rich in their sensorial experience; and to the level on which a user is able to influence and/or manipulate the content inside those environments. With these definitions in hand, we can carry on with a broader idea of what VR is and that although it is heavily tied to certain technologies, it is the vividness and interactivity what ultimately allows us to judge how the technology advances. This is important given that many authors have built a timeline of modern VR mostly around the hardware advances. Most of the timelines start with a machine called Sensorama developed by filmographer Morten Heilig in 1955 (see figure 2), which was capable of playing short films while also making use of touch, sound, and scent, in addition of full peripheral view. The experience was enhanced by films being in color and images displayed as three dimensional [4]. A few years later, Sutherland wrote "The Ultimate Display", a paper on which he describes a theoretical device that would be able to both display and give stimuli to the user [37]. A few years later, Sutherland created a device nicknamed "The Sword of Damocles" [36]. The device used head tracking, a display in each eye, and computer-generated imagery to present a stereoscopic display (see figure 2). This is considered today as the first Head-Mounted Display, and where the story of current devices can be traced to.

A lot of advances were made in the following decades. The 90s saw a commercial increase on the development of hardware and software for VR. Companies such as Sega (Sega VR console) and Disney (DisneyQuest VR Theme Parks) started

Figure 2: Left: Sensorama. Right: The Sword of Damocles.

experimenting with VR technology. A general sense of popularity in the media through articles, TV and film predicted the market to skyrocket in the following years. Nevertheless the hype of VR started to go down by 1996 and all through the first decade of the 2000s saw little development. This period was dubbed the “VR Winter” [18]. In the book The VR Book, the author Jason Jerald mentions what was missing during this time was a wider field of view. In 2012 the first prototype of Oculus rift was presented at the E3 convention (see figure 3). Since this moment a new era of VR devices and software has seen a quick rise until today [18]. The device able to produce a 1280×800 resolution (640×800 per eye) with a 16:10 aspect ratio, along with a 90° and 110 FOV horizontal and vertical respectively.

Figure 3: Oculus Development Kit 1, circa 2012.

As of the time of this writing, the leading VR hardware from Oculus, the Oculus Rift S, is able to produce a resolution of 2560×1440 (1280×1440 per eye) with a 115° vertical FOV (see figure 4). Added to this, the hardware has inside out tracking for 6° DOF controllers. Microsoft, Google, Valve, an other companies involved in the development of hardware for immersive experiences are producing similar hardware.

Most technologists agree that this hardware race is driving the manufacturing costs down as well as lowering the entry barriers to consumers. More importantly, the VR landscape is now able to offer different levels of quality depending on what consumers want to spend [30].

Figure 4: Oculus Rift S. Released May 21, 2019.

2.2 User Interaction in Virtual Reality

Sutherland's head-tracking device to determine a viewer's angle is possibly the first 3D interaction technique. At the time most devices of it's kind were cumbersome and it was impractical to develop many applications for VR. In the 80's and early 90's 3D stereoscopic computer graphics, miniature CRT displays, position-tracking systems, and interaction devices such as the VPL DataGlov, allowed VR systems to grow. Even though not much 3D interaction was available outside of head-tracking there were already experiments enabling users to interact with the world. Examples of that era interactions were Visualization of 3D scientific datasets, real-time walkthroughs of architectural structures, and even VR games. These games provided opportunities to look into faster, more realistic graphics; more accurate head-tracking; lower latency; and better VR software toolkits. Nevertheless, these experiments were restricted to a small group such as computer scientists and engineers from the computer graphics community. Improvements in VR such as decreased latency and improved accuracy in position and orientation tracking allowed for more complex applications to be created but the knowledge on 3D interfaces was still not existing [22]. Around the same point in time, personal computers had matured and a lot of research regarding principles of good user interfaces [27], design and development processes aimed at ensuring usability [16] and models that explained how humans process information when interacting with systems [6].

The use of the existing user interaction has been helpful exploring new interaction in 3D. But there are many situations that either don't translate easily or simply do not exist. For example, fatigue after long use of hand gestures, how to type letters in an immersive environment, or even as simple as moving oneself inside it [22]. Inside of VR the design space is no longer constrained by the real world physics. This allows experimentation with new 3D interfaces. Having so many options also poses a problem for 3D interaction designers having to choose or create new ones until mature guidelines are created. These problems are what gave way to the area of 3D Interaction Design and it becoming a part of HCI. Advancements in the hardware as of this writing have allowed a lot of 3D user interface exploration. With time many common tasks have become identified and made into metaphors such as Selection, Grasping, Pointing and Surface (dragging, rotating) [22].

As of this writing there are too many adapted metaphors to dive into all of them. There are a couple of research groups that I believe are worth mentioning and the work they are doing. One of them is led by Mike Alger who in 2015 create the VR Design Manifesto. The manifesto was a video presentation along with a document which together described the idea of Environment Design [2]. He further explains that environment design involved bringing in knowledge common to architects and interior designers in the real world. Alger has created basic guidelines regarding positioning of 3D elements in space based on previous research about human physiological constraints in eye gaze, head movement and focal distances. For example, research shows that our eyes strain to focus on objects as they get closer to our face until we are eventually cross-eyed. The distance where this starts to become noticeable is about 0.5 - 1 meters. The same research shows that there is a distance range in VR where objects displayed appear as 3D, outside of this range object may appear flat, or cause strain in the eyes [9]. See figure 5.

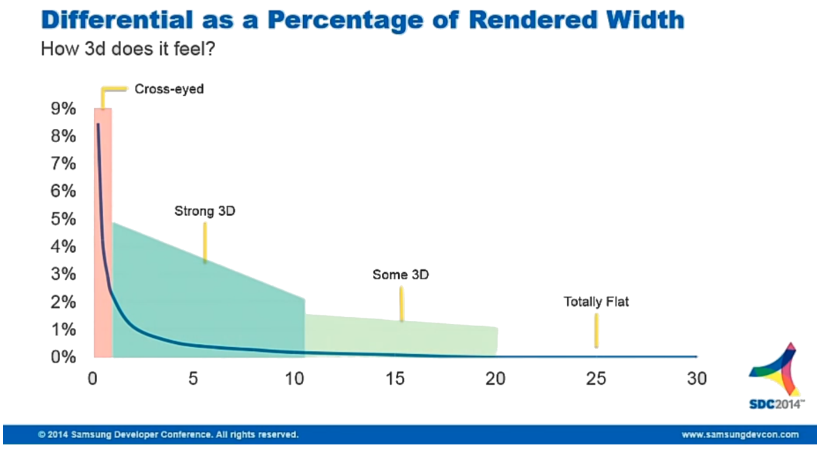

Figure 5: Level of 3D feeling based on distance. [9]

Similar information was further processed by Alger to define what he called VR Content Zone. These are the areas where information maintains 3D aspect, words are legible and no strain is caused on the eyes. The zones are measured in meters for distance, and degrees for angles. His work has set the current accepted guidelines for what are comfortable areas of operation inside VR. Figure 6 shows these content zoned in the context of a seated immersive experience.

Another researcher from Google AR program, Josh Carpenter, has moved forward with similar ideas. While working at Mozilla, his research group explored how to bring exploration elements to VR in the web. His work is particularly relevant to consuming content, one of the principal tasks in a browser. An example of their findings had to do with bringing regular website media to a 3D environment. His team found that organizing content in a 360cm-wide 2D canvas and then applying that canvas as a texture for a cylinder had positive feedback and made the experience very intuitive (see figure 7). [7]

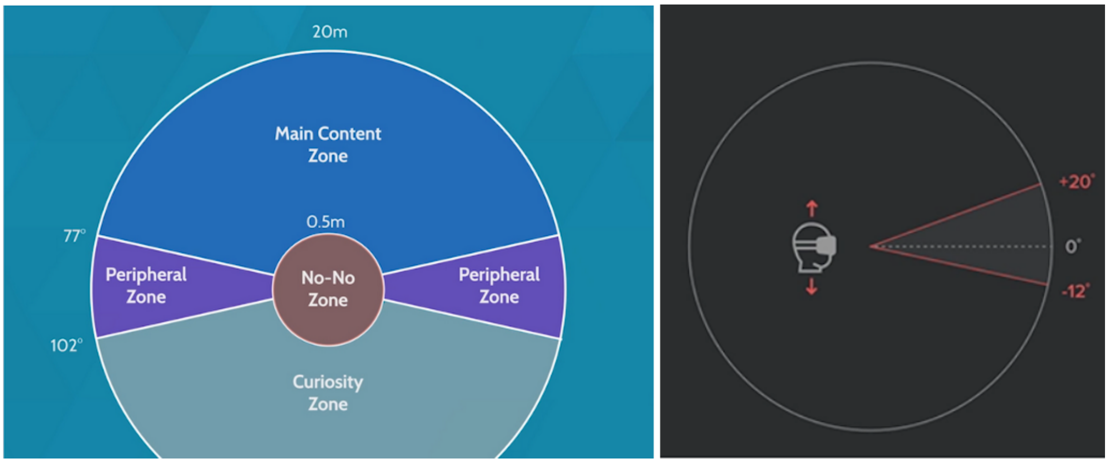

Figure 6: Comfortable content zones [3].

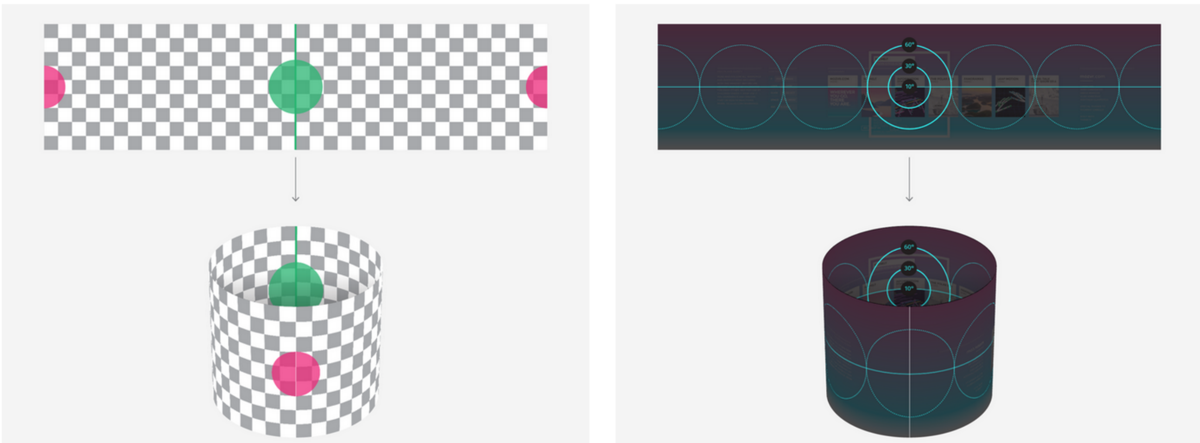

Figure 7: Content created on a 2D wide-screen, then applied to the inside face of a cylinder. Cylinder is place around user's POV [7].

2.3 Video Game Design

We based our approach extensively in the MDA framework [17]. The framework stands for Mechanics, Dynamics, Aesthetics. It aims at bridging the gap between game design, development and analysis. Moreover, it's 3 levels of abstraction allow the designers to decompose the overall game experience and use it to iterate its design, research process, and analysis (see figure 8).

Mechanics refers to the specific components of the game at the level of data representation and algorithms. Dynamics describes behaviors of elements inside the game, where they are directly or indirectly caused by the user; and the element outputs affect the user's experience and vice versa. Aesthetics refers to the user's emotional response produced by the game or its elements.

The framework goes on to synthesize a useful vocabulary to be used during the game design process, in particular regarding the aesthetics of the game. The vocabulary consists of 8 words that describe the goal of any game: Sensation, Fantasy,

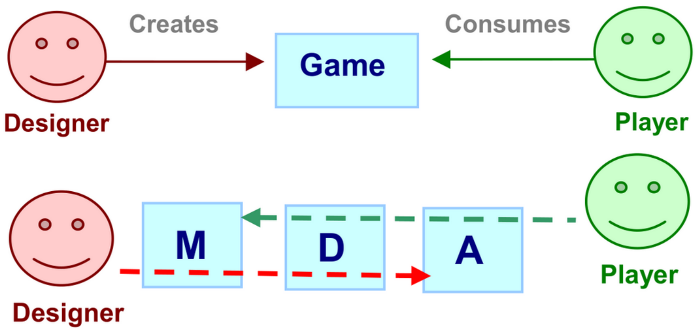

Figure 8: MDA Framework. [17]

Narrative, Challenge, Fellowship, Discovery, Expression and submission. Using these words one can describe the general aesthetics goals of a game.

Although not normally used in game design, Design Thinking is a methodology that provides a solution-based approach to solving problems. Design thinking uses an iterative approach that puts focus on understanding the user, and working through that understanding to reach a solution to their problems. A key perspective is the attempt to understand the problem through the users eyes and not through assumption of the designer (see figure 9). We incorporated elements from design thinking in our process. The main reason is that although the MDA framework really is focus on gaming, whereas our project required more understanding of current problems. By utilizing design thinking methodology we are able to explore a problem-solution approach in the early stages of the design. In the section Game Design we expand on how this was used in our project.

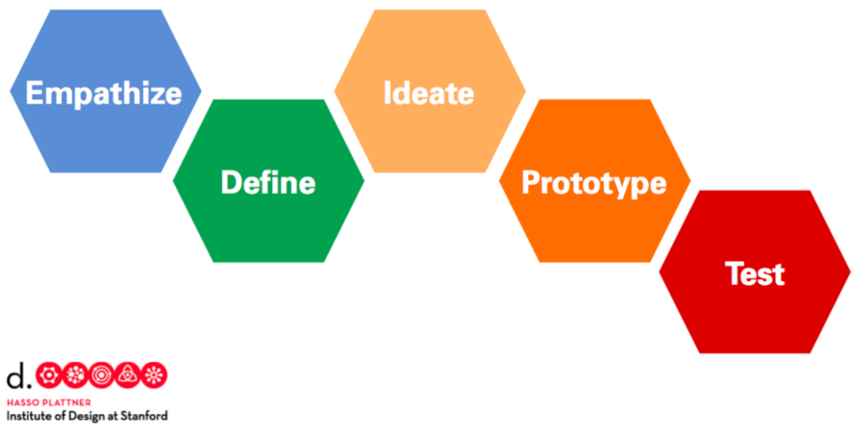

Figure 9: Design thinking process from Stanford's Design School.

2.4 Serious Games

A serious game is one designed for a primary purpose other than pure entertainment. Serious games, also known as game-based learning, is any game that aims to enhance the player's knowledge. They use pedagogy to influence the experience instruction, whereas a regular game follows an entertainment-only approach. Serious games are related to regular games during the design phase, where project owners need to work together with people familiar with pedagogy and subject-matter expert to insert activities that educate or instruct inside the game [42], see figure 10. Serious games attempt to leverage the instincts of cooperation, interaction and imagination, by using instructive materials. The hope is that serious games can elevate learning through utilizing the strengths of gaming [32]. Studies in several domains suggests so. Shin et al. [33], conducted research in the domain of mathematics where they observed the use of serious games in classrooms had positive effect on the learning outcomes. The effects were present regardless of the previous ability of the students [33].

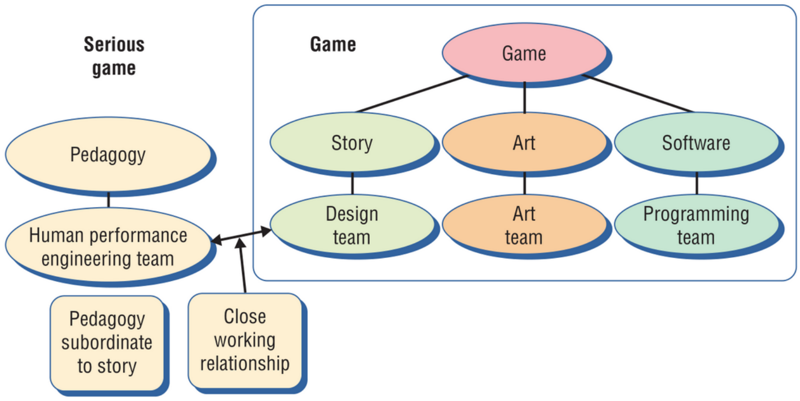

Figure 10: Relationship between game design and Serious game development [42].

The research on serious games has been growing rapidly for over a decade [21]. Articles in this topic have seen exponential growth since the 90s, suggesting a close relationship with the growth of the same industry (see figure 11).

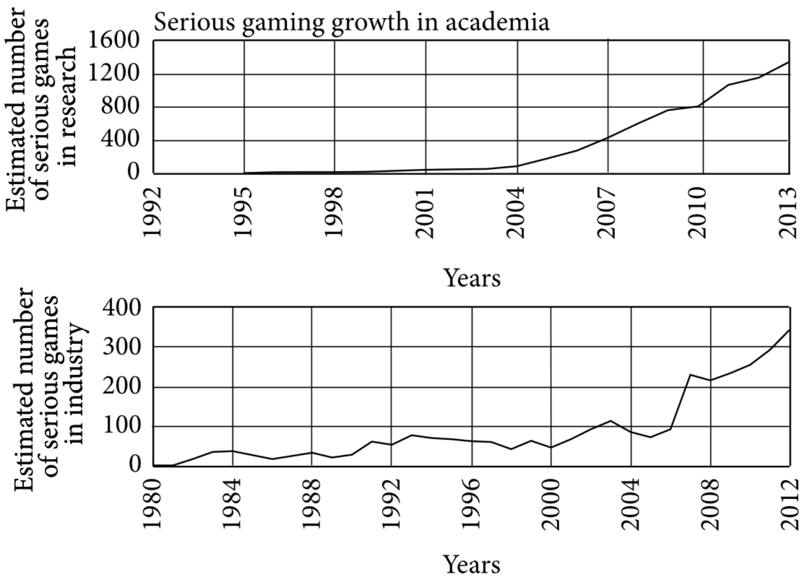

Figure 11: Top: Increase of serious game topic in research, Bottom: Increase of serious games in the gaming industry [21].

3 Game Design

This section describes the first part of my internship. The project aims at the exploration of using VR to facilitate learning. Moreover, the project leaders suggested that the use of an immersive environment could potentially offer advantages over traditional didactic approaches currently used in classrooms. Besides the immersive component, the project is related to learning physics in the classroom. We produced a small framework to think about the different areas that the project would be looking after. This framework was organized by 3 broad areas: Immersive technologies (VR), Serious gaming, and Physics learning (see figure 1). We followed design thinking steps: empathize, describe, ideate, prototype, and test (see figure 9). This is an iterative methodology formalized and taught at Stanford's D-School. The first part of the project then focused on learning about the real problem existing users are facing. We used semi-structured interviews to learn more about them, what they currently enjoy of the learning process and what they disliked. Later we collected all the information we gathered from them and tried to find patterns across the data using post-it notes. The results were further structured and polished and those became our set of problems to work with. We applied several methodologies for brainstorming solutions like Brainwriting 635 [29]. It consists of 6 participants supervised by a moderator who are required to write down 3 ideas on a specific worksheet within 5 minutes, this produces a large amount of ideas in a short amount of time. This method had to be modified to fit our constraints but we were still able to produce a big set of solutions. Those solutions were later parsed and organized from most to least relevant. We used this final list to have an ideation process. Going one by one we developed more specific ideas and solutions for each of the problem groups previously gathered. Finally we had a different brainstorming session to think about how our favorite ideas and solutions could be mixed into a common theme or game. The results were then presented to our supervisor and interested parties. Below I will provide details on how this work was divided into several sessions and the results from each of them.

3.1 Design Process

3.1.1 Defining target users

At the beginning of the process it was very important to define who would be the target audience for this project. Initially the ideas were too broad, using VR to help people learn physics. When questioning project leaders about more details the only answer we had at this point was that it wasn't restricted to any one type of user. I took the approach of inquiring from our physics didactics advisor to talk more about what's the order in which the topics are taught and, based on her research, which topics do students seem to struggle the most. From this conversation we learned that Newtonian physics seems to be the area that causes more confusion not only with students but also with adults who've gone through the education system. Newtonian physics, also known as classical mechanics, is the area that describes the motion of macroscopic objects, from projectiles to parts of machinery, and astronomical objects, such as spacecraft, planets, stars and galaxies. We also learned that a particular topics people carry their misconceptions into adulthood is projectile motion.

We followed up the discussion to better understand what is the current system doing to teach this topic, and at what age are these topics covered. Our didactics advisor mentioned some of the exercises done in class: measuring falling objects, calculating trajectories, etc. She commented on some of these exercises are done with technological tools such as tablets. Regarding the age range we learned that the curricale is shifting but the topic is expected to have been covered in the lycée. This corresponds to ages 16 to 18 years old. With this information we proposed and it was agreed to target students in France, 16-18 years of age, currently learning projectile motion topics in their classroom.

3.1.2 Semi-structured interviews

Having selected the target users we moved on to the next step which was listening from them what is the current status quo. What is it that they like or dislike about the current way they are learning about this topic. For this purpose we attempted to find interviewees with the exact description as our target users. Due to time and language constraints, we worked instead with french university students which were able to speak English and who had taken the Newtonian physics course in their *lycée*. Details about the semi-structured interviews are listed below:

- 4 participants
- Ages 20-23
- 2 males, 2 females
- They attended *lycée* in France and took the physics courses at school. Except one who took the biology courses.
- Only notes were collected in these informal interviews.
- Collected across several days and lasted from 30min to 1h.

We obtained a lot of insights from these interviews. To begin with, we got better acquainted with the education system in french high school from the students perspective. Up until this point we had only learn some from reading and from our advisors. One interesting piece of information was that not all students get the same amount of physics when dealing with Newtonian physics. Although all of them will pass through it, depending on the area of study the student has chosen, some may have a couple hours less per week of it.

Another interesting piece of data that was common across the interviews was an experiment in their chemistry class about making soap. When asked about their favorite experiments all of them mention this one. The reason seemed to be about being able to create something through several steps along the way and observe the final product. The educational goal of the experiment was aimed at learning how to use instruments inside a chemistry lab. Nevertheless the constructive and hands-on elements of it was that ultimately made it a favorite.

We also learned about their negative experiences. I won't go into all the details but a common comment seemed to be regarding exercises or experiment that involved just observation. Most interviewees mentioned experiments with gravity involving very little activity and them previously knowing what would happen. This assurance of knowing the result seems to take out any interest they may have in the activity itself. One could argue this loss of interest before starting may affect them observing the activity at all and thus missing some key learnings. These are examples of interesting data we got from our interviews. A lot more was gathered and processed as the next sections will show.

3.1.3 Parsing Data

Overall we collected several pages or data with a lot of key insights. We dedicated a session to work with the raw information. Using post-it notes we wrote down all key insights from our interviews and tried to cluster them around similar topics. We found 3 main topics to work with: 1) People: How people feel about teaching methods; 2) Activities: Level of engagement from the activities currently used; 3) Education system: Practical elements from the teaching system itself.

3.1.4 Brainstorming solutions

We used the 3 main areas identified to have a brainstorming activity. Having new understanding of the problems directly from the users was key to be able to perform this activity since the creativity required to perform it is dependent on the level of empathy the participants of the activity have on the users and the problem. As mentioned before we used a technique called brain-writing. Brain-writing aims to develop a high amount of ideas in a short amount of time. We used 3 pages, the same amount of the topics found and titled them accordingly. Then each person had 3 minutes to write as many ideas related to that topic as possible. The ideas were encouraged to be anything, including crazy or outrageous. After the 3 minutes passed we shifted the pages and the process was repeated again until we were able to complete 3 rounds. The result was 20 ideas or possible solutions. We continued to explain the written ideas to each other and then rated each according to which we liked best or at least seemed like an interesting path to explore. The final count of usable ideas came down to 14:

1. Use one example to cover several topics.
2. Make teachers tell physics jokes in the classroom.
3. Encouraging creativity (add Easter eggs, rethink grading homework).
4. System should have different material for different type of people.
5. Choose your own adventure.

6. Difficult of prediction (for exercises).
7. Switch the current model Theory-Practice-Theory once in a while.
8. Have more time for activities (or freedom to do them later).
9. Professors = students; more conversation, more confidence for students.
10. Custom activities per student.
11. Objectives should not be obvious.
12. Teacher could be a tour guide (not a monologue).
13. Non-standard examples.
14. Free time for education (more freedom in the schedule).

3.1.5 Solution development

The next step in the design process was to talk more about how these subset of ideas could be expanded and applied in a game situation. Starting from the top rated ideas we brainstormed each of them how they could be applied in a game. At this point we made use of the MDA Framework for developing video games [17]. The framework provided us with the vocabulary needed to express how a solution could be used in the game, what we could expect from it, and how it contributed to the overall experience. For example when discussing one of the ideas "different content for different people", the MDA framework (Mechanics-Dynamics-Aesthetics) suggests thinking first about the aesthetics, or how we want the user to feel.

The idea of different content came from user interviews where some students really enjoy one particular exercise but others found it boring. They explained the reason these were boring was because it did not seem appealing to them to perform the exercise. A way to make things more appealing to a user is by having a design that matches their style or mood. Perhaps allowing certain customization of the environment. Perhaps by changing the color scheme or overall scenery, the experience could be more pleasing to the eye and potentially less boring from the beginning. The ability to customize different aspects of the game relates to the dynamics of the game according to the MDA framework. Similarly, the required steps a user needs to take to make it happen would be the mechanics.

One key element we developed was that of having a storyline. Our background research suggested that storytelling and narrative are key elements to create a feeling of presence or immersion [18]. This led us to select a game style called choose your own adventure. This style involves having an initial story that branches out based on users choices throughout the game. This will result in a unique path for each user.

3.1.6 Game topic

The last step in the design process was to think about the game as a whole. This was our least structure brainstorm in the process. Our goal was not to finalize a story or narrative but instead to think about general ideas that could later be used to build a story. We came up with 3 ideas: 1) A cargo drop, where a user needs to aim and drop object to hit a target; 2) Mountain momentum, where a user would be placed in a platform which is being balanced on its center and movable elements of different weights allow the platform to be stable; 3) using gravity blocks to observe movement of objects when they pass through them.

The first idea involved launching or dropping object from above the ground while moving. The idea would allow to observe projectile motion in different angles and to observe from a birds-eye-view. It would also be straightforward to add goals and levels of difficulty. The downside is that any experience in VR that involves constant movement and some degree of concentration is prone to cause cybersickness. Cybersickness occurs when exposure to virtual environment cause similar symptoms to that of motion sickness. The condition is commonly associated by visually-induced perception of self motion [23]. After some feedback we decided to let this idea go. The second idea, mountain momentum, would involve a user being represented on a 3D platform along with other moving objects. The platform is kept in equilibrium from its center thanks to the weight displacement on it including the user's. This equilibrium is at risk when the other weights around the platform move, making the user having to move to keep equilibrium. We enjoyed this idea but were cautious about how would the moving mechanism for the user work and how extensible it could be. In different levels, more weight could be added, or the point of equilibrium could be moved from the center to anywhere else in the platform to increase difficulty. Finally, we explored the idea of gravity blocks. In this idea there are cubes or boxes in our immersive environment that have different physics rules inside of them. For example, one box could be made to have gravity 5 times the one we are used to. This would in turn allow us to observe an object falling through it at a higher speed. Extending this idea, the gravity to be aiming not downwards but sideways, making object thrown into it to change the direction of their trajectory. The mechanics could be extended to change other physical behaviors inside that box. For example, instead of changing gravity value and direction, one could apply a strong wind, different viscosity of liquids (water, oil, jello), and more. A combination of several boxed could later be used to form a type of 3D puzzle.

Based on all the above we decided to move forward with the 3rd option. One of the main reasons is that it seems to provide more flexibility and space to extend in the 3 dimensions of the framework (Mechanics, Dynamics, Aesthetics). The 3 ideas were presented to the supervisor and our physics advisor who agreed to move forward with the idea code-named “Gravity Blocks”.

3.2 Game Development

After finding the topic and creating a list of game elements (dynamics) we closed the Game Design process at this stage. Developing an immersive serious games is a long term process. Attempting to achieve goals in several different areas (immersion, education, entertainment, etc) will require more time and resources. The results of this game design sprint will continue to be used as the long-term basis for the Jeseipa project. Nevertheless, one of the key game elements selected involved a display to shoot at a target which distance is too far to be aimed at by the naked eye. There are many ways to display the positional and geographical location of different objects to a user. This served as a start point to the research part of this project which is described in the next section.

4 Spatial Interaction Research

As mentioned at the end of the previous section, the outcome of the design phase provided the opportunity to perform quantitative and qualitative experiment on display user interfaces. In a regular physics learning environment, students are used to observing trajectory in a 2D plane though their books or in a device screen. There are several examples online that help a student visualize the phenomena [25]. A common example of projectile motion involves a cannon shooting with an observer at a distance. The spectator (a person looking at an image which has both the cannon and the target) is able to observe the initial and end position of the projectile from an equal distance and perspective (see figure 12). Some more advanced simulation may display 3D visuals but the vast majority continue to follow the same presentation style and analysis on 2 planes. Most simulations and learning descriptions for this topic involve a 2D representation the forces involved in terms of X and Y, the horizontal and vertical planes. Our initial analysis led to a discussion of the different methods to display the sae information to the user in 3D.

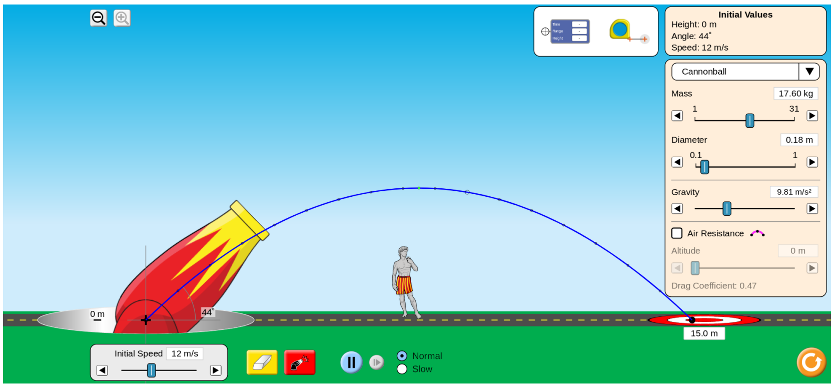

Figure 12: Visualization of projectile motion in 2D [25].

4.1 Camera Views

In an immersive environment the common default view is a *First Person View*. Where the virtual camera is positioned at the same place as the user's eyes [39]. Another are variations of first person view is the *Third Person Style Centering*, where the camera is fixed on the Y axis and is pointing towards the player's character, usually with a constant distance. An example of this is shown in figure 13. Other common perspectives in 3D include: Aways Over The Shoulder, Camera Lock-On and Free Rotating Camera. Although both the perspectives are quite common in 3D gaming, immersive gaming introduces head movement. This creates a problem with some of the perspectives mentioned above. Cybersickness describes the presence motion sickness symptoms while, or after, using virtual environment technologies. It can be developed due to fast movement of the camera. The effects are more noticeable when the user is not in control of the camera movement. Nevertheless more factors are known to contribute to cybersickness [23]. Another limitation with many of the known perspectives is that in an immersive world, control of the camera could be key in the usage of the application, not only for displacement but for general awareness of the environment. All these reasons made it clear that camera perspective should not be modified in our spatial user interface design. The camera perspective should remain the first person view which is the default in most current immersive applications today.

Figure 13: *Left*: First person view inside a 3D game [11]. *Right*: Third Person Style view inside a 3D game [8].

4.2 3D User Interfaces

Following our exploration of camera perspectives we explored the idea of representing different camera views through a 3D user interface. Through the rest of this document we use the terms *3D user interface* and *3D user widget* interchangeably, referring to any 3-dimensional element in an immersive environment with input that supports 3 or more degrees of freedom (DoF). In the context of this project one of the first obvious ideas to display the desired information regarding projectile motion involved a 2D screen or display where the camera is positioned at a distance between the user and the projectile target such that the trajectory is visible. Such widget would simply display the 2D representation students are already accustomed to (see figure 14). This representation is also know as an isometric projection, hence the interface name *Isometric 2D Display*. Adapting from the real world is one of the true-and-tested approach to developing UIs [5]. For this reason we considered this approach to be one viable option for our problem.

Figure 14 shows a popular game played through a 2D screen. It's input systems are either a touch interface or mouse and keyboard. We would need to adapt this interface to our project in an immersive environment. We also wanted to explore a different way to represent the information that would make use of the 3D nature of the immersive world. Stoakley et al [35] developed a user interaction technique which is a miniature copy of the virtual environment. This interaction technique is called World in Miniature (WIM). WIMs can be thought of the VR counterpart of scale models, such as the ones found in museums(see figure 15). These models allow an observe to create a mental map of size, position and other properties of large objects or areas (see figure 15.a). The ideas so far around Jeseipa require observation and path planning tasks for a projectile. WIM interfaces are already common in

Figure 14: Isometric 2D Camera Display. User is able to observe both starting point and target location at the same time. All objects sizes are accurately represented. [13].

video games. In a VR version of popular game Minecraft, a 3D minimap is available for the user to understand their position in the environment (see figure 15.b). The widget allows the user to understand the height and distance of different places in the environment at the same time. Similarly, the user is able to quickly understand the location of several element in the 3D space. We believe this same analogy could be applied when trying to understand the three-dimensional position of a target when launching a projectile.

(a)

(b)

Figure 15: *a*): Scale model of the tower of london [28]. *b*): Screenshot showing WIM implementation in MinecraftVR [38].

These 2 options, the isometric 2D display and the WIM, were discussed in our team. We spoke about how each interface's benefits and downsides as well as how different users may prefer one over the other. The game design so far would at some point require users in an immersive environment to perform the following tasks:

1. Understand their position relative to the environment.
2. Understand an object position relative to the himself.

3. Accurately aim a projectile towards a target.

4. Observe the trajectory that a projectile takes after they have launched it.

As mentioned before, literature on WIM suggests that it is a useful tool for users to understand their location in a new environment and locomotion [19]. This also suggests that a WIM interface could be a good candidate to comply with tasks 1 and 2. Not a lot of information was found regarding tasks 3 and 4 inside an immersive environment. On the other hand, the isometric 2D display seems to have the opposite benefits. Aiming and observing trajectory are relevant for Jeseipa project to explore. These are already being used in teaching and games for the same purposes. One more display technique is that of allowing the user to observe the trajectory before the projectile is launched (similar to the game play in Angry Birds [13]). This ability becomes more relevant in a 3D space, where the target distance directly affects the visibility for the user. Our initial tests in the virtual environment suggested that this would be a necessary visual aid for the users working along the 2D and 3D interfaces mentioned so far. In the following sections we continue to explain the process to refine the interfaces into something that would be useful for Jeseipa's use case.

4.3 Spatial Design

The brainstorming around 3D user interfaces focused our interest in how to show projectile motion information to the users in a way that allows them to be both active and passive. Active when launching a projectile at long distances. They need to be able to observe parts of the environment where they have not been before. Passive when the projectile is in motion. The design should allow them to observe the physics phenomena normally shown through 2D simulations. The rest of the time available for the master internship project was dedicated to the design, development and testing of these 2 widgets: the isometric 2D display and the world in miniature implementation. One more 3D display technique was that of the trajectory before launch, allowing a user to observe the expected path beforehand. The side camera used a relatively simple implementation. In out initial tests, the implemented isometric 2D display was position fixed to the user's POV. This was a decision inspired in existing video games that show added information in the screen, showing information about the environment in a corner of the screen at all times. One immediate drawback had to do with the hardware available. Although the FOV in our hardware is generous, the focus area is only in the center of the screen. This is due to a known visual artifact when using fresnel lenses [1] (more details about this artifact are described in the Hardware section). The artifact makes this implementation unusable due to the focus area on the hardware. Morever, the fixed position perspective based on the user character's gaze orientation was not usable either. The screen content moves based on the user's physical head position and

[1]Optical component used as an alternative to a conventional lens due to it being lighter and more cost-effective. A Fresnel lens is made of several concentric grooves etched into a substrate such as plastic. Due to their characteristics, this type of lens is capable of focusing light similar to a conventional lens while being physically narrow in profile [41].

rotation which felt disorienting. Added to this, relevant objects such as the target to be hit would leave the visual area due to the angle and direction of the user's head. Based on all the above we decided to remove the display out of the fixed FOV and turne it into an interactable object. This change made it behave like any other element inside the virtual environment, making it easier to understand. Another discovery during the initial tests had to do the visual perspective on the display. The initial implementation used a common perspective projection camera. We quickly realized that the available isometric projection [2] was more fitting for our use case (see figure 16). The isometric projection is familiar to more students since it is the same used when learning about projectile motion in books and simulations.

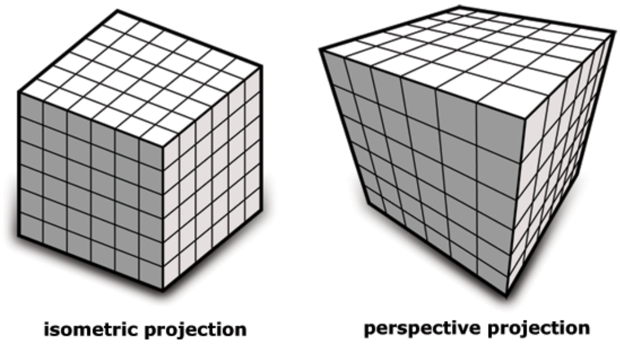

Figure 16: Difference between isometric and perspective projections.

The WIM widget required less design process to reach a working version. More details about the technical implementation strategies are described later in the Software section. The main design decisions had to to with the size of the WIM. It needed to be big enough to be able to observe details inside the environment, but small enough for the user to walk around it. During development we were satisfied with the scaling of the world. Nevertheless, we noticed that elements such as the projectile, target and others needed to be bigger. We extended our implementation to allow for individual elements to have unique scaling factors when represented inside the WIM. This allowed us to play with the values until we found the ones that looked better. The final versions of both the isometric 2D display and the WIM are shown in figure 17. We used these design to continue the process of experimentation around the research question. Further technical details, planning and execution of the experiments are presented in the next section.

[2]An isometric projection is one that allows us to see all 3D objects represented in a 2D space.

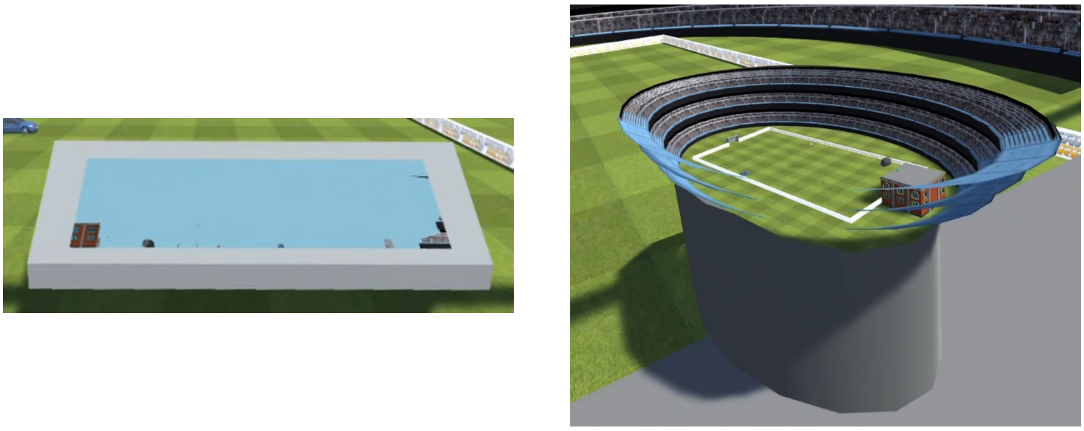

Figure 17: Final design of isometric 2D display (*left*) and World in Miniature(*right*).

5 Methodology and Implementation

To observe and measure the difference between these widgets a prototype was developed. The prototype allowed a user to perform the same task with both the isometric 2D display and the WIM. It allowed an experimenter to manage the order on which the widgets are presented (more details in the Software Architecture section). The also allowed a user to be in control of the input system and actions. Based on the game design achievements, the prototype allowed a user to launch a projectile. The prototype made use of as several game elements previously considered. Most importantly, the prototype allowed our team to make measurements from the experiment. The ultimate goal of the prototype, codenamed *Projectile Dysfunction*, was to evaluate the widgets around the research question. Below we describe the prototype developed to understand which immersive widget provides better performance at hitting a target at a distance using Unity for implementation. We describe several challenges found during the development of the prototype such as: selecting the relevant hardware, logging all relevant data points during the experiment, displaying accurate physics representations in VR, and designing a user experience method to gather qualitative data. We go through each of these challenges explaining in detail their characteristics and how they were solved. The chapter begins by describing the visual description of the immersive environment we attempted to achieve. Then, we describe the hardware choice, its technical characteristics and its limitations. Next, an overview of the software architecture is described. The requirements are explained as well as the design choices. The third section described the plan to gather qualitative data and the motivation behind it. The final section describes the experiment design and how the pieces tied together.

5.1 Environment Design

Our prototype had few guidelines from the beginning. Our background research suggested that a familiar environment can help with the feeling of presence [1]. Also, the environment dimension should be of enough size such that a user is able to observe the projectile movement from their POV. In other words, it should not contain elements that would occlude the view. The environment should produce 3D sounds, this was easily attainable through Unity. The environment should also be walled such that the horizon is occluded. A soccer field inside a stadium also served this purpose. Another important design decision was allowing the user to visualize the trajectory of a projectile before it was launched. In the real world our visibility is affected by different natural conditions such as sand, fog, dust, etc. Visibility inside VR, regarding object far away from the user, is ruled by the hardware being used. Moreover, our initial tests confirmed that a visible trajectory was necessary for the tasks to be achieved in the amount of time the experiment would require. Most of the details in the rest of the design were defined through trial and error at the laboratory with colleagues.

5.2 Hardware

The purpose of this prototype is to create as close representation for the future work the VENISE team will pursue as part of the Jeseipa project. There are 2 main issues to be solved regarding the selection of the hardware for this:

1. A setup that allows 6 DoF.
2. A cost efficient setup given the expected requirement for a school.

The project had preselected the Lenovo Explorer Mixed Reality headset and controllers (see figure 18). The headset uses a 2880×1440 (1440×1440 per eye) display, has a Refresh Rate of 90Hz, a Field of View 110 Degree and uses Fresnel lenses for optics. The controllers have a 6DOF tracking system, they feature a direction pad, analog stick, Windows key, menu button, rear trigger and a bumper style button on the inside of each. The controllers communicate via bluetooth [14]. All of the above was running on a Razer Blade 14in laptop (4k, 2014), running a Nvidia RTX 1060 VR-ready GPU. An important note on the device optics is regarding the fresnel lens. Using fresnel lenses to reduce weight and size of an HMD is a common practice with most of the leading HMD manufacturers. There are other benefits regarding image quality due to the distance between the eyes and the display inside the HMD, but a key disadvantage in our experiment is that the objects outside the centarl area of the displays will appear blurry [41]. Details on how this side effect relates to the current paper are discussed in the Results and Discussion sections.

Figure 18: Lenovo Mixed Reality [14].

5.3 Software Architecture

The prototype followed a simple *game controller* system. For development, Unity3D version 2018.4 was used. This is the latest Long Term Release version of this software as of the time of this writing. The programming language chosen for this project is C#. This is also the language available to work with Unity by default. For the

VR framework we selected the Microsoft Mixed Reality toolkit version 2 RC2.1 [26]. Microsoft started releasing the next iteration of this framework on February 21st, 2019 as a Beta release candidate. The framework offered better compatibility with Unity as well as custom code to be used with the latest version of their devices. This was useful as the selected hardware previously mentioned is from the same Microsoft family, Windows Mixed Reality. Limitations of the framework were learned in the process. Some limitations had their roots in the framework‘s novelty as it was a beta version, and some other had to do with the small amount of experience using it. The overall architecture of our system is quite simple (see figure 19). There is a main controller in charge of setting up the experiment based on a prepared CSV file. The CSV file contains the information relevant to the session an individual participant would go through. More information about how the sessions were organized are further described in the Experiment Design section. Each line on the CSV file is parsed as a data structure and placed into an array. We named this data structure *Trial*. This array contains the the values for each task a participant had to accomplish, such as the distance of the target, which widget is to be used next, and some others.

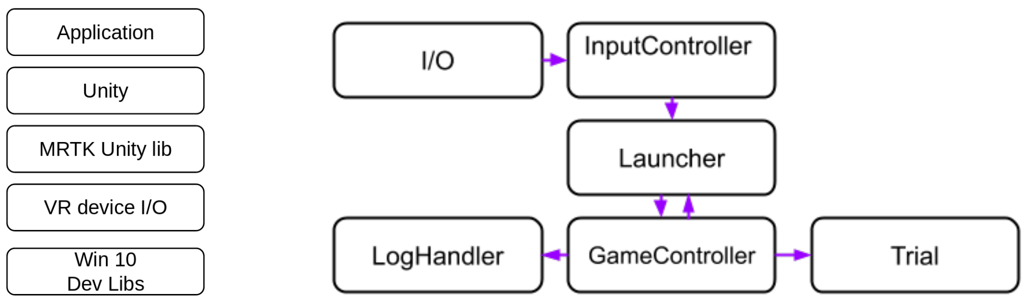

Figure 19: *Left*: Mixed Reality system stack. *Right*: Prototype architecture.

The implementation of the isometric 2D display was created in Unity with the provided elements in the IDE. Unity cameras can be configured to use regular perspective mode or isometric mode. One can also configure them to output the camera view into a *Render Texture*. This texture was applied into an *ImageUI* component. There was some work to be done regarding dimensions of the *ImageUI* component versus the camera. An isometric (also called orhographic) camera in Unity needs to have a 1:1 aspect ratio. The viewing area we need to display has a widescreen ratio. For this reason we created an array of cameras and an array of *Image UIs* with the same amount of elements each. There was no scripting needed during this implementation, only aesthetics components were added. The WIM interface had to be scripted since there is no default implementation in Unity or its *assetstore*. An initial approach consisted on the miniaturization of an element by creating a new *mesh* and recreating the vector points based on the desired scale. One a new mesh is created one can easily remove points in the mesh that are too close together since the element will be miniaturized. This could improve performance and would be useful if a lot of elements are becoming part of the WIM. This works for primitives and simple elements, nevertheless it becomes more complicated once there are elements with complex shapes. This also implies recreating materials and textures if some decorations would be involved. Due to its complexity and lack of scalability we did not go through this implementation strategy. A second strategy for the WIM implementation relied on *cloning* the elements. The process is simple but uses more resources if the elements to be cloned are more complex than primitives. Given our specific requirements for the prototype this was not a problem. Moving forward with this strategy meant attaching a script to the elements that needs to be part of the WIM. A dedicated WIM object expects to receive registration from those elements. Elements also announce to the WIM object their desired scaling factor relative to the prepared WIM environment at the time of registration. The WIM object returns a reference to their miniaturized clone and each of the elements is then responsible for updating their position and rotation on each Update. This behavior is exemplified in figure 20.

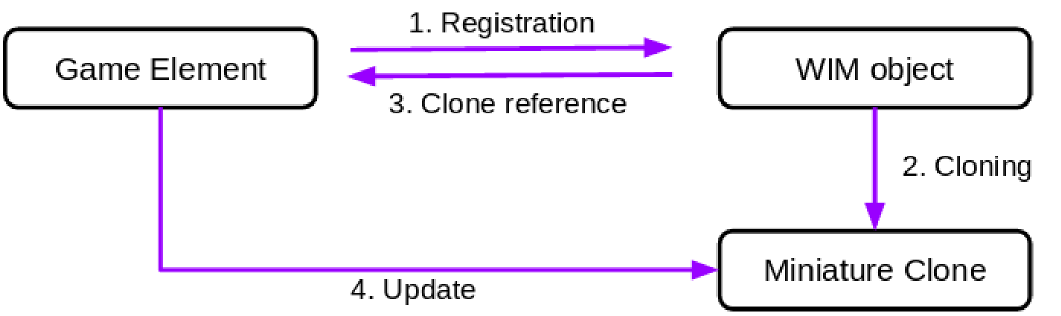

Figure 20: WIM technical implementation in Unity.

5.4 Data Collection

Below we describe the data collected through the prototype, both quantitative and qualitative. From the quantitative perspective, the intention was to measure users performance when attempting to hit a target. We defined performance based on 2 general measurements: the time it takes a participant to make the decision to shoot measured in seconds, and the amount of shots a participant takes to hit the target measured as an integer error count. The data is collected as a data structure during the participant's session. After each *trial* is completed, the values are passed to a log handler and saved into a CSV file in the system. Measuring the decision time allows us to observe participants' confidence based on what the widgets are showing them. An argument can be made that shorter aiming times would point at a better visualization, more on this in the *Discussion* section. Similarly, the error count is taken into account. Every extra shot can be considered an error. The data was later analyzed using statistical tool R-studio. In summary, the scope of this project is to measure and analyze aiming time and error rate. Nevertheless the system implementation collects more quantitative data. The system is always logging user's input actions and their direct effects. For instance, every time the user clicks on the button to increase the power, this action is logged along with the new power value.

Another log implementation is that of all the relevant objects position, rotations and scales. This wasn't challenging to implement since there are only a handful of movable items at any given time:

1. The user's hand: this holds the projectile launcher in the form of a *gun*.
2. The projectile: A simple spherical object.
3. The user's gaze: This is represented as the virtual camera attached to the user's head mounted display information.

The information is collected in the form of an array of *Vector3* data structures. These are then passed to the log handler and stored as a json file in the system. As mentioned before, we also collect qualitative data. For this purpose we created a set of simple questions to gather information about the exercise in the areas of their physical comfort and their preferences for the available widgets. At the end of each experiment we conducted semi-structured interviews to gather details about their preferences and any opinions they may have formed on how to improve the widgets. With the participants explicit permission, we recorded the audio of those interviews. At the same time, observations were collected during the prototype operation, taking advantage of the fact that the experimenter is able to see what the participant is seeing at the same time, the experimenter took notice of several items such as the way participants held the controller, live commentary users made out loud, as well as overall body language. As part of the predefined questions, the participants were asked to mention any type of physiological discomfort they may have experienced, including but not limited to nausea, dizziness or headaches, followed by questions about their perceptions of the graphics in the prototype. Afterwards the participants were asked to order the 3 modes of engagement (world in miniature, isometric 2D display, and none) from most favorite to least favorite. Finally, the participants were asked about their choices in a semi-structured interview with questions such as “What did you like about your most favorite?”, “What did you dislike about the least favorite?” and “What would you change about it to make it?”.

5.5 Experiment Design

In the study we wanted to test which widgets would provide improved performance. To have base line of comparison, the experiment included a condition where there was no widget at all to help the participants. We used a within-subjects design with the 2 widgets (WIM and isometric 2D display) and a no-widget condition. We also have 2 sub-conditions: height of the target with 3 levels; and distance of the target with 2 levels. The dependent variables were the amount of shots needed to hit the target and the amount of time needed by a person to take a shot (measured from the moment the target is shown). During the experiment planning we used Touchstone [12], a tool which allows researchers to design controlled experiments. The tool takes dependent and independent variables, the amount of participants and trial duration, and it outputs the attained order effect coverage, total experiment session time and statistical power attained given the conditions. As mentioned earlier, there are 2 sub-conditions: height and distance. Each of them have 3 and 2 levels respectively. The distance the values are 40 or 85 meters. The height values are: Below Eye Level (-8.5m), at Eye Level (1.5m, accounting for a person's average height), and Above Eye Level (12m). Using this tool we were able to plan recruiting 24 participants to have a statistical power above 0.8 with Cohen's f=0.25. Specifically a power of 0.91 would be achieved (see figure 21). Moreover, the tool outputs a CSV file containing a full trial table, this is the exact order in which each participant is to have the independent variables presented to them on each trial on each session. This is the CSV that would be used with the VR application so that the experiment would proceed automatically.

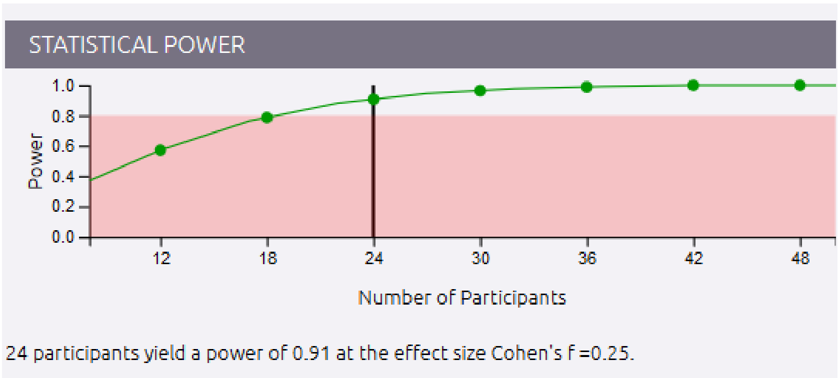

Figure 21: WIM technical implementation in Unity.

5.5.1 Participants

24 participants (12 female, 12 male) were recruited for this experiment. The age range was 20 to 50 (mean 28.4). Most participants were somewhat familiar with virtual reality. Half of the participants had previous experience using a VR device, the other half had never used a VR device before. All participants were right-handed.

5.6 Procedure

Participants were invited to join and given a consent form as well as a minimal questionnaire (see appendix D). After these forms we explained there would be a small verbal introduction about the project and tasks. We also mentioned that before starting the experiment we would have a practical training session. We started with the introduction where we explained the main task for the participant: to shoot a target at a distance. We explained there was no time limit for the tasks and no scoring would take place. We also explained there will be a couple widget that will help them achieve the goal and that they will get to learn and practice how the behave during the training. Regardless of their previous experience with VR we proceeded to explain the use of the controller. We explained that this prototype was implemented in such a way that only the relevant buttons on the controller were enabled, pressing any other button would have no effect. At this point they were free to touch and click the controller to familiarize with the weight and shape. Finally, we showed them the starting position of the experiment, marked on the floor and that they have about 2 meters radius to move around as they need. We then proceeded to start the training. It consisted of iterating through each of the 3 conditions performing the same task of the experiment. During the first iteration we encouraged the participant to not shoot immediately but instead to play with the controller, and to observe the widget from different angles. Each participant experienced the same training variables and got the chance to use each of the conditions 5 times. The participant's task for the experiment was to hit a target using the controller in their dominant hand. The controller is shaped as a sci-fi gun to clarify the purpose. The target is always the same: a red and white sphere with a diameter of 1 meter. As mentioned earlier, there are 2 sub-conditions besides the widget in use. Using the same Touchstone tool we selected a latin square to avoid carryover effects. The experimental matrix was 3x2x3 within-subjects, for a total of 18 experimental conditions and a total of 432 shooting actions. After each session, we invited the participants to sit down to have an informal interview. This interview was audio-recorded with their explicit consent. There were a few predefined questions to start the conversation. First we asked about any physiological discomfort including cybersickness. Then asked to provide an informal rating from 1 to 3 of the conditions they were presented with. The rating was in the context of best aid to performance. The rest of the interview was semi-structured, looking for information regarding the reasons for them to give that rating.

6 Results

In this chapter we discuss the results from our research questions defined in the *Spatial Interaction Research* section. First we present the quantitative results. Performance was measured in the amount of time it took participants to aim as well as the success rate of hitting the target. Results were loaded into R-studio software to generate a statistical analysis. The qualitative data is shown after. Qualitative results are shown in the context of user research. General feedback from the participants was analyzed and synthesized for this document.

6.1 Quantitative Results

The 2 dependent variables, average aiming time and the amount of shots fired, were measured in terms of seconds and as integer values respectively. The aiming time was measured from the moment the target appears on screen to the moment a participant fired a projectile. The success rate was measured by counting the amount of shots needed to hit the target in each trial. The initial quantitative results pointed at no direct difference between the 3 conditions for either the average aiming time or the amount of shots taken to hit the target(see tables 1 and 2). Figure 22 shows the graphs for Average Aiming Time and Error Count. The confidence interval are within the same range. A slight difference is observed between the isometric 2D display and the baseline when measuring error rate.

Table 1: Average aiming time results.

Independent Variable	AvgAimTime	c.i.
IsometricDisplay	11.88833	0.9854999
None	10.87961	0.8943101
WIM	11.82728	1.2165975

Table 2: Error count results.

Independent Variable	Error Count	c.i.
IsometricDisplay	1.555556	0.1706957
None	2.145833	0.2584179
WIM	1.916667	0.2233920

An anova test on the data observing the average aiming time shows no significant difference between the independent variables. On the other hand the same anova test on the data observing the **error count shows a significant effect ($\mathbf{F_{(2,46)} = 8, p < 0.001, \eta^2 = 0.12}$)**.

We tried to understand if any of the sub-conditions would have had a higher effect and perhaps give clues to more research. An analysis with each individual

Figure 22: *Left*: Average aiming time between independent variables. *Right*: Error count between independent variables.

sub-condition was performed. First we looked at how *height* affected each of the independent variables (see figure 23). Results show that there is still not a lot of difference in the amount of time it takes participants to aim. On the other hand, the error rate, or the amount of shots taken by each participant, seems to show more variability.

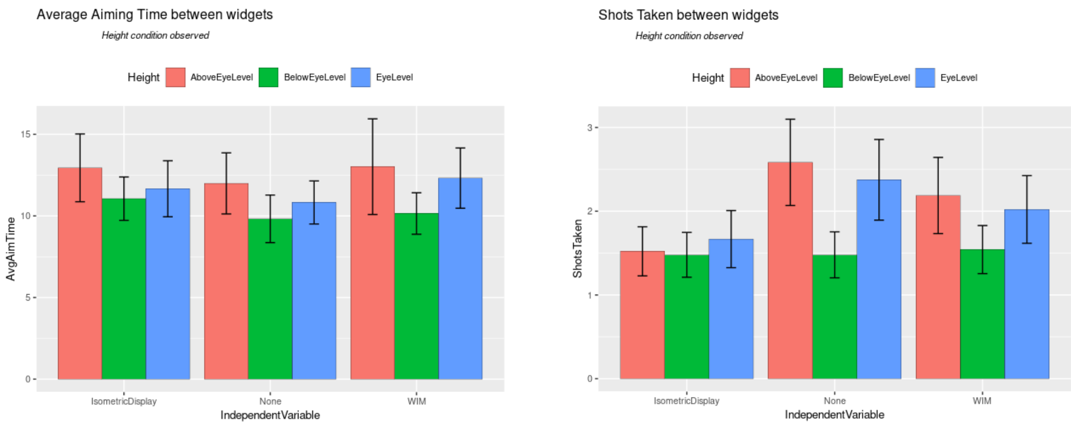

Figure 23: Analysis of average aiming time and error count withing the different *height* conditions.

We continued with the same observation for the *distance* condition. Similar to the height, these results continue to show a low significance on the average aiming time, and a higher difference between the amount of shots taken by participants. Figure 24 shows the clearer different on this condition.

These results suggest that the participants consider a similar amount of time required to make a shot. More research would be needed to understand what makes participants feel the need to shoot the projectile even when no clear shot is available. The observation here is that regardless of the conditions, the participants seem to take more or less the same amount of time to decide to shoot.

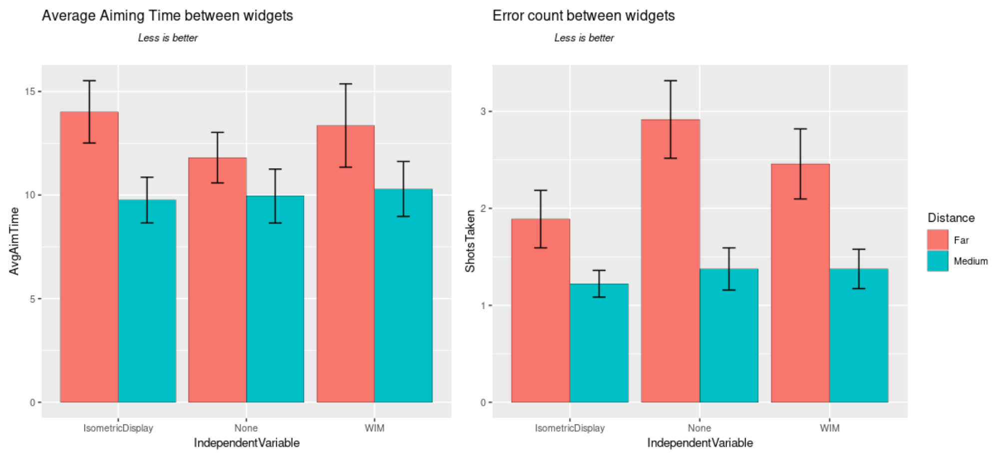

Figure 24: Analysis of average aiming time and error count withing the different *distance* conditions.

6.2 Qualitative Results

A lot of feedback was obtained During the exit interviews with the participants regarding several aspects of the experiment. The feedback can be grouped in 3 broad areas: physical discomfort, perception of accuracy or performance, and entertainment value. Below we dive deep into the analysis of all the observations and comments obtained in each of those areas.

6.2.1 Physical Discomfort

Only 3 out of the 24 participants reported some discomfort during the experiment. When asked about the details of this discomfort 2 of them involved placement of the headset as uncomfortable. They mentioned the headband may have been too tight but did not bother to correct it until the end of the experiment. The other participant experienced some slight headache towards the end of the experiment and refer to the discomfort as minimum but worth mentioning. The same participant also mentioned longer exposure could become uncomfortable mainly due to the specs limitations on the HMD, namely the blurriness on outside the center of the display area. This blurriness can be attributed to the fresnel lens side effect mentioned before. Another point of discomfort for users came from the video rendering itself. Heavy use of the hardware seemed to produce lag on all participant actions. For example, whenever a user clicked on a button on the controller, the corresponding action could take too long to be executed in the application. Physical clicks on the controller had a small but noticeable lag on the expected visual feedback inside the experiment. Similarly, as users move their heads, the video rendered followed almost immediately but with a delay big enough to be noticed. Although most participants did not encounter this issue this could be a future cause of cybersickness in more experiments running similar hardware specifications. These issues were presented when the hardware seemed to overheat after long term use.

6.2.2 Perception of accuracy and performance

At the end of each session, and as part of the informal interview, participants were asked which of the condition they considered offered the best performance. The conditions were: World in Miniature, orthographic camera display, and no widget. The results of the perceived performance is shown in figure 25.

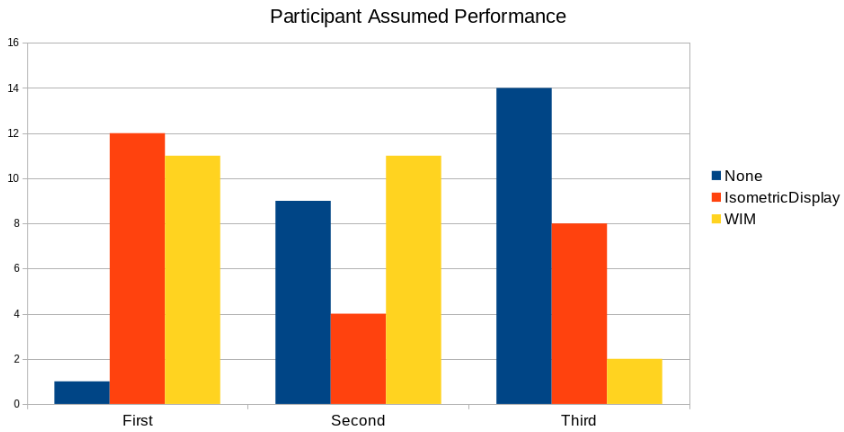

Figure 25: Perceived performance by participants immediately after finishing the experiment.

The results show that participants had a very similar opinion of what was best, but not what was second best. In other words, **the WIM widget was overall considered useful splitting most of the votes between first and second best choice. This is contrasted by the orthographic camera display, whose vote was split mostly between either the best or the worst of the option** (taking into account that having no widget at all was also an option).

Participants were asked about the reasons behind the rating on each of the widgets. After parsing all the information we believe there are 2 main decision points for them. The first one is related to the amount of general trust users give new technologies. Users that have had previous experience in VR or gaming tend to trust the information being presented to them by the widget, this resulted in the physical action of aiming using the widget and pulling the trigger once the trajectory matched the target. In contrast, people with no previous experience with VR or gaming seemed to have the need to verify that the information presented by the widget was correct. This verification happened in the form of turning their heads away from the widget and towards the target once the trajectory seemed to match in the WIM widget. The process of turning their heads created small movements in their hand that made them miss the target when pulling the trigger, thus causing frustration when missing. Most of them continued this behavior through the whole session, always having to look away from the widget to confirm the information being presented in it.

The other decision point had to do with a hardware issues previously discussed regarding fresnel lenses. In particular, the blurriness outside the center of the display made it difficult to focus on 2 items at the same time. For example, the orthographic camera display offers a great way to observe if the distance to the target is correct, but the direction of the shot needs to be corrected by looking at the actual target. This is happens due to the limitations of an orthographic projection to observe different angles. The issue reported by the participant happens when both the target is within the HMD display visibility at the same time as the orthographic camera display. The focus radius is too small making the participants choose between being able to observe only the virtual environment, or only the orthographic camera display. Attempting to keep both inside the FOV would cause both of them to be outside the focus radius hence rendering blurry.

6.2.3 Entertainment Value

An interesting finding from the interviews was a constant intention from several participants to give feedback about how to improve the "game" experience. These feedback mostly came during the process of asking about improvement on individual widgets. In other words, the participants seem to naturally assume a gameplay is what was hindering their performance or experience during the experiment. This was curious given that at no point was this presented as a game or any other experience of entertainment value. I believe the reason behind this behavior could be due to some design choices of the prototype itself such as using cartoonish elements around the game, the use of lowpoly[3] design, the choice of sound for actions, among others. Most possibly having a relatively challenging task in such a scenario may be the main contributor to having a relatively entertaining experience. Participants suggested changes that they felt could improve the entertainment value of their experience. Some of the suggestions were cosmetic and some where's enhancement on the available gameplay elements. As part of the informal interview, participants were asked about ways in which either the WIM or orthographic camera display could be improved. The question was mostly interpreted with adding new UI elements rather than changing elements of the widgets themselves. Below I detail some of the more interesting elements gotten from this feedback.

Trajectory change colors when matching the target
Participants mentioned that for the goal of aiding to hit the target, a visual cue letting them know the trajectory is in position would be very useful. As it is right now, the participant can still make mistakes with either widget. The reason is that with the orthographic camera display the user still needs to judge manually if the direction the target is hitting is correct. For the WIM the issue is about the angle between it and the user. For example FIGURE X, shows how the viewing angle has some ambiguity to tell if the trajectory in line with the target. This could be solved by the user moving around to get a better perspective but my observations from users was that when they had found a comfortable spot to perform the task, they

[3]Lowpoly is a polygon mesh in 3D computer graphics that has a relatively small number of polygons. Some artists and game developers use the resulting low-detail from a low polygon count as an aesthetic rather than as an optimization technique.

would rarely move. When asked about this phenomena some users commented that there was no reason to since the viewing angle was good enough.

Allow widgets to be manipulated

A common request from users was to allow widgets to be manipulable to their liking. The users reported that the stadium walls, although semi, transparent, were occluding their view. This occlusion forced them to move around to find a comfortable position. Several users mentioned it would be easier to move the WIM object rather than them walking around it to find the best position. Another suggested solution was to remove the walls of the stadium all together and keep only the field. A decision was made during this experiment for the widgets be fixed to the ground and the position was selected based on pre-trials and a pilot study. The reason behind it was realted to the time required to teach participants how to operate movement. The pilot tests also showed enough edge cases where users without enough training could end up confused about how to manipulate the widgets. Solutions to these and similar problems are proposed in the Discussion section below.

Color contrast between camera screen and trajectory elements

A common feedback for both widgets across most users was the low contrast between priority elements in the widgets(see figure 26). The trajectory in the prototype used a dark blue color material with no reflection. At the same time the material pattern of the stadium benches contained similar enough colors that at some point the trajectory is hard to observe using the WIM widget. A similar situation happens with the target (red and white material) depending on the angle. A simple solution would be to choose a higher-contrast palette for the UI elements. This palette would need to be manually created based on each scene and environment. The orthographic camera display presents a similar problem. Some users complained the sky blue color was too strong and close enough to the trajectory dark blue color. One suggested solution was to let the other side of the stadium be shown. The downside is that such projection would be even more noise with colors. A more plausible solution could be simple to change the sky blue color to something with more contrast.

Figure 26: Isometric display texture(cropped).

Elements size inside widgets

Users reported observation issues with both widgets. The isometric 2D display seems to show the biggest complain regarding the trajectory being too small to the liking of several users. The WIM showed less complaints in this area, most probably due to the scaling factors on the dynamic element of the environment (scale factor of 3.0 for the trajectory and of 2.0 for the projectile). A possible explanation for the need of more scaling could be related to the manipulation improvement mentioned before, as well as the contrast between the space and the elements material colors.

Add second orthographic display from top view (for direction)

The last common feedback between a number of users was that of the missing dimension on the isometric 2D display. As mentioned before, this widget only allowed for distance to be accurately observed but not the direction, making the users having to coordinate between looking at the widget and then aiming for distance manually. Some users suggested a second screen from a top view could be added alongside the current one to be able to observe both dimensions in the panel.

7 Discussion

In this section we discuss the results of the prototype and experiment from a broader perspective. The feedback on spatial interfaces are reviewed in a broader sense as well as their relevance in the current project. Advice based on the learning of this project is given to improve the interfaces as well. We also discuss the overall experience of making the prototype as well as suggestion on what could be done differently would a similar project arise. Finally we discuss ideas of future research areas to be explored derived from this work.

7.1 Experiment

Several participants pointed out the gamified feeling from the experiment. Although it was explained at the beginning there were no game mechanisms, many participants gave feedback on how to improve it. The referred to “the game” when talking about the experiment. This seems to suggest that existing elements are already pointing in the right direction. One of the elements that probably contirbuted contributed to this feeling was the lowpoly design. Lowpoly is a design trend used in many games today. This trend might be part of the association between the look and feel of the experiment with an actual game. Another element is the sounds chosen for the experiment. The action sounds (shoot, increase power, decrease power) were taken from game resources found online. Similarly the sound chosen for the environment was that of *cheering in a stadium*. It could be possible the cheering sound contributed to the feeling of competition and thus of a game experience. These and other elements in the experiment could be further developed to bring a stronger immersive gaming environment for the user. For instance, adding more elements that produce sound. Elements that may be part of the environment which adds more 3D audio sources in the scene. These elements do not need to be manipulable. Being able to produce sound can bring a stronger immersive feeling. Similarly, lowpoly design seems to have a positive response from users. As mentioned before, how immersive the experience feels has no direct relationship with photorealism and thus could be leveraged to create a friendly environment for learning.

7.2 3D Interfaces

Although the results showed no direct performance difference between the widgets, it was interesting to see how the data behaved when focusing on one of the sub-conditions. One possible modification on the experiment could be to increase the values. The current design seems to suggest our 2 widgets do not provide a big enough advantage over aiming without them. This does not mean there is no use for them. Increasing the difficulty of achieving the goal may show more significance in performance. As our quantitative data showed that distance seems to have a strong effect on the need for either widget. Also, more conditions need to be explored. Currently the target is always facing the user. Having the target placed at different locations in the horizontal plane might also increase the significance of performance.

Regarding the widgets as technical features, we find the implementation of each is simple with some caveats. One relevant feedback from the WIM interface is that it was unnecessary to draw all the environment. In the case of the stadium, the tall walls interfered with the user's view. Even though there was some transparency to them, they bothered some users. The current implementation has no way to modify a model on the go. A custom model could be provided that removes some of the clutter. That would mean there is a specific perspective that benefits the user though and the choice is made for them. Another option would be to develop a different implementation that is able to remove non-prioritized elements between the users POV in a designated area in the environment. More design choices would be needed, and implementation does not seem simple. For the time being, and based on project requirements, designating only relevant elements to be included in the environment seems like the best option. This and some careful consideration on the environment beforehand could simplify the process. For example, making sure the environment has no elements that are too tall, or if they are not relevant enough, to have them removed from the WIM. With he isometric 2D display there are more constraints. Unless a new implementation is defined, the display is limited by the features included in the Unity pipeline (camera > texture > material > model). Increasing the size of the objects can be done by duplicating each of the relevant elements and configuring one to be visible by the camera only. There would be performance drawbacks with this solution since elements that are heavy on resources like trajectory and projectile may make the game lag. If the elements can be kept to a minimum this could be one solution. Increasing contrast also seems to be a clear choice going forward. Outside these comments most of the complaints had to do with the hardware restrictions already explained. Some users mentioned the need to confirm what they saw in the WIM was in fact the same as what was happening in the virtual environment. They had no specific explanation for this, nevertheless the interviews seemed to show that people who are more comfortable with technology and/or video games are faster to trust what they were seeing in the WIM without hesitating. People who are less used to video games reacted the opposite. More data is required to draw conclusions from this. One thing to consider is that this could be an opportunity to increase user engagement by allowing them to switch between interfaces at will. Also having the added benefit of a more personalized experience.

Finally, during the experiment design a decision was made to fix the size and position of the widgets. Previously during internal tests, widgets were able to be moved, rotated, and scaled at the users will. The decision to disable this features was a practical concern since it would increase the training time for each users' session. Moreover if some participants would struggle to learn how to use these features it would also interfere with the performance results. After going through the experiment we believe this would not be a problem anymore. Most users were able to pick up the 3 interactions almost immediately. Adding a few more controller interactions to learn how to manipulate objects inside the environment should not pose a great problem. One last thing to take into account is the implementation of the manipulation of objects inside the virtual environment. Using the MRTK library, a developer is able to easily enable this for every desired object. Nevertheless, the default controller layout to manipulate them conflicts with the implementation of our prototype. Further work and exploration of controller layout is needed to find one that is suitable for all the actions we wish to perform during the game. At the same time, the landscape of helper modules to develop VR interactions is growing rapidly. We can expect these issues to be minimized as the APIs mature.

7.3 Game Design

Overall the immersive POV seemed very natural to most participants. During training session some of the participants took longer to understand that their movements in real life were reproduced in the virtual environment. Although this was not specifically tackled in the interview, we suspect having no body in the immersive environment contributed to some confusion. They were able to track the position of their hand since the gun model was attached to it. That said, there was no hand representation itself. I believe adding visual tracking of their hands and/or body in the virtual environment could greatly increase the sense of presence. The MDA Framework proved to be a great tool to design thinking techniques. It helped establish a path and direction for the brainstorming sessions. It also was of great help when discussions were skewing strongly to technical implementation at an early stage. Using the framework to step back into the dynamics or even aesthetics kept the conversations in context. I encourage all future work to also continue along the path of these frameworks regardless of how the interaction and user engagements move in priority through the rest of the Jeseipa project.

7.4 Future Work

This project took a strong focus in spatial interaction. The long term goals of this project has a broader list of inquiries for research including education, hardware and software. Tackling so many dimensions could be challenging and the process of game development is long. One way to keep up with the research areas would be to bring more involvement from educational researchers into the research team. Designing an experiment to measure learning requires knowledge in pedagogy and possibly into more specific subareas of the field. It can become infeasible to break down each area into smaller parts. Perhaps another approach would be to finalize a game design that can be agreed upon by the educational advisor. Once the design is approved, further research can focus on individual elements of HCI, Engineering or Education. The game would serve only as a testbed for the individual fields to use.

The research work of this project focused on 2 spatial user interfaces. As mentioned before, spatial interaction is a relatively new field with vast areas to explore. I believe with stronger definition of the long term project, more spatial UIs could be utilized and tested. Each new finding on any spatial interaction UI or technique will be of great contribution to the field.

8 Summary

This study had 2 main goals at its conception: to use design thinking techniques to help define the long-term form and objectives of the project, and to perform quantitative analyses on spatial user interfaces. The first requirement, developing the plan and a prototype for the project, was handed by the local laboratory, whereas the analysis on spatial interaction was motivated by the interest on learning about the research process on the field. Regarding the use of design techniques the biggest challenge was found with the team acceptance of the design processes. The long term project required several sign-offs from different participants and not all were on board with spending time in the design section. Nevertheless after the first session of gathering information the team started to see the value. Their interest and acceptance of the design processes increased as the sessions showed relevant results. The result of the process was a game idea and a set of game elements to be used in the project. The game involves a user shooting projectile through special elements which have a physics modifier inside. An element, for example a translucent cube, will apply physical forces to any object inside of it. These forces can be customized to make object behave as if they were moving inside viscous liquids, or through a gravity field. These elements could be stacked in a certain way such that a user needs to make use of them for a projectile to reach a target.

These results provided the chance to question how can a user be enabled to successfully aim and hit a target through these objects. Using spatial user interfaces we can provide users a way to visualize their position in the environment, that of other relevant objects and even the expected trajectory before shooting. We defined and developed 2 user interfaces (widgets) to aid the user with this task: a WIM and an isometric 2D display. This allowed us to define a research question for the following parts: *When comparing 2 spatial interfaces, a WIM and an isometric 2D display, which one offers the better success rate when attempting to hit a target and which one is preferred by the users?*. The rest of the project was dedicated to the design of an experiment that would allow us to answer this question. The implementation of the experiment used the MRTK library. One challenge with it was its beta status and the lack of documentation available to speed up our learning process. Other challenges involved architectural decisions. We made compromises on scalability over development speed due to the short time available. Another challenge was widget placement as well as controller gestures which had to be discarded due to the selected hardware, a Lenovo Explorer. These limitations are explained and discussed in section 5. The experiment compared both widgets as well as having no widget at all. The results showed that there is a significant difference in the success rate between an isometric 2D display and using no widget. There is no significant difference between the 2 widgets though. The qualitative results showed the 2 widgets were equally preferred as their top choice, but the same isometric 2D display had more users undecided between it being the best or the worst choice. In contrast, the WIM had most users agreeing it was either their 1st or 2nd choice. Besides the quantitative results, user feedback was gathered to improve both user interfaces as well as the interaction techniques used with them.

References

[1] Mike Alger. “Visual design methods for virtual reality”. London, UK, Sept. 15, 2015. URL: http://aperturesciencellc.com/vr/VisualDesignMethodsforVR_MikeAlger.pdf (visited on 07/28/2019).

[2] Mike Alger. *VR Interface Design Manifesto*. In collab. with Mike Alger. Jan. 6, 2015. URL: https://www.youtube.com/watch?v=n3b8hZ5NV2E (visited on 08/22/2019).

[3] Mike Alger. *VR Interface Design Pre-Visualisation Methods*. In collab. with Mike Alger. Oct. 4, 2015. URL: https://www.youtube.com/watch?v=id86HeV-Vb8 (visited on 09/17/2019).

[4] Tom Ball. *From Pygmalion to Oculus Rift: The History of VR*. Computer Business Review. Nov. 20, 2017. URL: https://www.cbronline.com/emerging-technology/pygmalion-oculus-rift-history-vr/ (visited on 08/22/2019).

[5] Doug A. Bowman. “3D User Interfaces”. In: *The Encyclopedia of Human-Computer Interaction*. 2nd. Interaction Design Foundation, 2014. ISBN: 9788792964. URL: https://www.interaction-design.org/literature/book/the-encyclopedia-of-human-computer-interaction-2nd-ed/3d-user-interfaces.

[6] Stuartk Card, THOMASP MORAN, and Allen Newell. “The model human processor- An engineering model of human performance”. In: *Handbook of perception and human performance.* 2.45 (1986).

[7] Josh Carpenter. *VR Browser Explorations*. Josh Carpenter. 2014. URL: http://www.joshcarpenter.ca/vr-browsing-explorations (visited on 07/02/2019).

[8] Guy Carver. *The Elder Scrolls V: Skyrim*. Nov. 11, 2011.

[9] Alex Chu. *VR Design: Transitioning from a 2D to 3D Design Paradigm*. Nov. 19, 2014. URL: https://www.youtube.com/watch?v=XjnHr_6WSqo (visited on 08/22/2019).

[10] George Coates. “Program from Invisible Site-a virtual sho, a multimedia performance work presented by George Coates Performance Works”. In: *San Francisco, CA* (Mar. 1992).

[11] Cédric Decelle. *Far Cry 3*. Nov. 29, 2012. URL: https://www.ubisoft.com/en-us/game/far-cry-3.

[12] Alexander Eiselmayer et al. “Touchstone2: An Interactive Environment for Exploring Trade-offs in HCI Experiment Design”. In: *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. CHI ’19. Glasgow, Scotland Uk: ACM, 2019, 217:1–217:11. ISBN: 978-1-4503-5970-2. DOI: 10.1145/3290605.3300447. URL: http://doi.acm.org/10.1145/3290605.3300447.

[13] Rovio Entertainment. *Angry Birds 2*. July 30, 2015. (Visited on 07/20/2019).

[14] Will Georgiadis. *Lenovo Explorer mixed reality headset review: WMR headsets disappear from Microsoft store*. Expert Reviews. July 1, 2019. URL: https://www.expertreviews.co.uk/go/1408965 (visited on 07/23/2019).

[15] James J. Gibson. *The ecological approach to visual perception*. 1979. ISBN: 978-0-89859-959-6.

[16] Deborah Hix and H. Rex Hartson. *Developing User Interfaces: Ensuring Usability Through Product &Amp; Process*. New York, NY, USA: John Wiley & Sons, Inc., 1993. ISBN: 0-471-57813-4.

[17] Robin Hunicke, Marc LeBlanc, and Robert Zubek. "MDA: A formal approach to game design and game research". In: *Proceedings of the AAAI Workshop on Challenges in Game AI*. Vol. 4. 2004, p. 1722. URL: https://www.aaai.org/Papers/Workshops/2004/WS-04-04/WS04-04-001.pdf.

[18] Jason Jerald. *The VR Book: Human-Centered Design for Virtual Reality*. New York, NY, USA: Association for Computing Machinery and Morgan & Claypool, 2016. ISBN: 978-1-970001-12-9.

[19] Joseph Kotlarek, I-Chen Lin, and Kwan-Liu Ma. "Improving Spatial Orientation in Immersive Environments". In: *Proceedings of the Symposium on Spatial User Interaction*. SUI '18. event-place: Berlin, Germany. New York, NY, USA: ACM, 2018, pp. 79–88. ISBN: 978-1-4503-5708-1. DOI: 10.1145/3267782.3267792. URL: http://doi.acm.org/10.1145/3267782.3267792 (visited on 08/22/2019).

[20] Myron W. Krueger. *Artificial Reality II*. 2nd ed. Addison-Wesley Professional, May 1991. ISBN: 978-0-201-52260-0.

[21] Fedwa Laamarti, Mohamad Eid, and Abdulmotaleb El Saddik. "An Overview of Serious Games". In: *Int. J. Comput. Games Technol.* 2014 (Jan. 2014), 11:11–11:11. ISSN: 1687-7047. DOI: 10.1155/2014/358152. URL: http://dx.doi.org/10.1155/2014/358152 (visited on 08/22/2019).

[22] Joseph J LaViola Jr et al. *3D user interfaces: theory and practice*. 2nd. Addison-Wesley Professional, Apr. 9, 2017. 624 pp. ISBN: 978-0-13-403432-4.

[23] Joseph J. LaViola Jr. "A Discussion of Cybersickness in Virtual Environments". In: *SIGCHI Bull.* 32.1 (Jan. 2000), pp. 47–56. ISSN: 0736-6906. DOI: 10.1145/333329.333344. URL: http://doi.acm.org/10.1145/333329.333344 (visited on 08/22/2019).

[24] Brett Leonard. *The lawnmower man*. Mar. 6, 1992.

[25] Andrea Lin. *Projectile Motion*. Phet Interactive Simulations. 2019. URL: https://phet.colorado.edu/sims/html/projectile-motion/latest/projectile-motion_en.html (visited on 07/19/2019).

[26] Microsoft. *What is the Mixed Reality Toolkit*. Mixed Reality toolkit Documentation. URL: https://microsoft.github.io/MixedRealityToolkit-Unity/README.html (visited on 07/23/2019).

[27] Jakob Nielsen and Rolf Molich. "Heuristic evaluation of user interfaces". In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM, Mar. 1, 1990, pp. 249–256. ISBN: 978-0-201-50932-8. DOI: 10.1145/97243.97281. URL: http://dl.acm.org/citation.cfm?id=97243.97281 (visited on 08/22/2019).

[28] Onofre_Bouvila. *A scale model of the Tower of London*. Wikimedia Commons. Aug. 1, 2006. URL: https://commons.wikimedia.org/wiki/File:Scale_Model_Of_The_Tower_Of_London_In_The_Tower_Of_London.jpg (visited on 07/23/2019).

[29] B Rhorbach. "Kreative nach Regeln: Methode 635, eine neue Technik zum Losen von Problemen". In: *Absatzwirtschaft* 12 (1969), pp. 73–75.

[30] Adi Robertson. *It's 2019 — which VR headsets can you actually buy?* The Verge. May 16, 2019. URL: https://www.theverge.com/2019/5/16/18625238/vr-virtual-reality-headsets-oculus-quest-valve-index-htc-vive-nintendo-labo-vr-2019 (visited on 07/02/2019).

[31] Rhonda Robinson, Michael Molenda, and Landra Rezabek. "Facilitating Learning". In: *Educational Technology*. 2nd. Routledge, Jan. 11, 2013, p. 384. ISBN: 978-0-8058-5861-7. URL: https://doi.org/10.4324/9780203054000.

[32] Ben Sawyer. *Improving public policy through game-based learning and simulation, foresight and governance project: Woodrow Wilson International Center for Scholars, Digitalmill, Inc, 2002*. 2002.

[33] Namsoo Shin et al. "Effects of game technology on elementary student learning in mathematics". In: *British Journal of Educational Technology* 43.4 (2012), pp. 540–560. ISSN: 1467-8535. DOI: 10.1111/j.1467-8535.2011.01197.x. URL: https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1467-8535.2011.01197.x (visited on 08/22/2019).

[34] Jonathan Steuer. "Defining Virtual Reality: Dimensions Determining Telepresence". In: *Journal of Communication* 42.4 (1992), pp. 73–93. ISSN: 1460-2466. DOI: 10.1111/j.1460-2466.1992.tb00812.x. URL: https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1460-2466.1992.tb00812.x (visited on 08/22/2019).

[35] Richard Stoakley, Matthew J. Conway, and Randy Pausch. "Virtual Reality on a WIM: Interactive Worlds in Miniature". In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. CHI '95. event-place: Denver, Colorado, USA. New York, NY, USA: ACM Press/Addison-Wesley Publishing Co., 1995, pp. 265–272. ISBN: 978-0-201-84705-5. DOI: 10.1145/223904.223938. URL: http://dx.doi.org/10.1145/223904.223938 (visited on 08/22/2019).

[36] Ivan E. Sutherland. "A Head-Mounted Three-Dimensional Display". In: *AFIPS Conference Proceedings (1968) 33, I*. 1968, pp. 757–764.

[37] Ivan E. Sutherland. "The Ultimate Display". In: *Proceedings of the IFIP Congress*. 1965, pp. 506–508.

[38] ThnxCya. *Minecraft 1.10 VIRTUAL REALITY UPDATE! | Minecraft VR April Fools 2016*. Apr. 1, 2016. URL: https://www.youtube.com/watch?v=ap6sQgAPQxo (visited on 07/20/2019).

[39] TV Tropes Contributors. *Various Video Game Views*. TV Tropes. 2011. URL: https://tvtropes.org/pmwiki/pmwiki.php/Main/VariousVideogameViews (visited on 07/18/2019).

[40] Stanley G Weinbaum. *Pygmalion's spectacles*. Vol. 6/35. Wonder Stories, June 1935. 48 pp. ISBN: 978-1-4444-5846-6.

[41] XinReality Contributors. *Fresnel lens*. Virtual Reality and Augmented Reality Wiki. Oct. 31, 2017. URL: https://xinreality.com/wiki/Fresnel_lens (visited on 07/22/2019).

[42] M. Zyda. "From visual simulation to virtual reality to games". In: *Computer* 38.9 (Sept. 2005), pp. 25–32. ISSN: 0018-9162. DOI: 10.1109/MC.2005.297.